ENGINEERING & PHYSICS · KINDERGARTEN–GRADE 8 · QUICK REFERENCE

Engineering & Physics (K–8 · Machines · Structures)

Grades K–8 · 3 pages

Newton's laws and simple machines, forces in structures, bridges and buildings, Ohm's law, circuits, motors and electronics, water and the grid, buoyancy and ships, the four forces of flight, rockets and robots.

1 Forces & machines · 2 Bridges & buildings · 3 Electricity · 4 Utilities · 5 Boats & ships · 6 Flight & robots

1 FORCES, MOTION & MACHINES

unit 1 · Newton, Archimedes, Galileo

Newton's three laws

Law	Says	See it
1 · Inertia	a thing keeps doing what it is doing until a force acts	a ball rolls until friction stops it; seat belts
2 · F = ma	force = mass × acceleration; more push, more speed-up; more mass, less	a loaded wagon is harder to start
3 · Action–reaction	every push has an equal push back	a balloon rocket; a rowboat moves back as the oar pushes water

Push and pull

A **force** is a push or a pull, measured in newtons (N). **Gravity** pulls down; **friction** resists sliding; a **net force** of zero means balanced (no speed-up). **Weight** = mass × g (g ≈ 9.8 m/s²). Speed = distance ÷ time; **acceleration** = change in speed ÷ time.

Simple machines

Machine	How it helps	Example
lever	a bar on a fulcrum; long effort arm, big lift	seesaw, crowbar, wheelbarrow
pulley	a wheel for a rope; more ropes, less effort	flag pole, crane, Archimedes' ship
wheel and axle	a big wheel turns a small axle	doorknob, bicycle
inclined plane	a ramp: longer path, less force	ramp, road up a hill
wedge	two ramps that split	axe, knife, nail
screw	a ramp wrapped around a post	screw, Archimedes' water screw, jar lid

Mechanical advantage = load ÷ effort (or effort distance ÷ load distance). A machine trades distance for force; it never gives free **work** (work = force × distance).

Gears, energy, engines

- **Gear ratio** = teeth on the driven gear ÷ teeth on the driver: a 10-tooth driving a 30-tooth turns it ⅓ as fast with 3× the turning force. Clocks: pendulum and escapement.
- **Energy** is the ability to do work: **potential** (stored: height, a spring) and **kinetic** (motion). A roller coaster trades one for the other; energy is conserved.
- **Momentum** = mass × velocity; crumple zones lengthen a crash to lessen the force.
- **Engines:** steam (Watt), gasoline (intake, compression, power, exhaust), electric motors.

MEMORY TRICK **The design process**

Ask (criteria, constraints) → **Imagine** → **Plan** → **Create** → **Test** → **Improve**. Keep an engineer's notebook. Failure is data.

2 BRIDGES & BUILDINGS

units 2–3 · structures

Forces in structures

Force	Means	Who resists it
compression	squeezing	columns, arches, stone
tension	stretching	cables, ropes, steel
shear	sliding past	bolts, beams at supports
torsion	twisting	shafts; Tacoma Narrows (1940)
bending	a beam sags: top squeezed, bottom stretched	I-beams, trusses

Loads

Dead load (the structure itself), **live load** (people, traffic, snow), **lateral load** (wind, earthquake). A **safety factor** builds in extra strength; a **load path** carries weight to the ground; **redundancy** gives a second path.

Bridge types

Type	How it works	Famous
beam	a flat span resting on supports; sags under load	log bridge, highway overpasses
arch	pushes the load outward into its abutments (compression)	Roman bridges, Pont du Gard
truss	triangles share the load as tension and compression	railroad bridges, Forth Bridge (cantilever)
suspension	deck hangs from cables over towers to anchorages	Brooklyn Bridge (Roeblings, 1883), Golden Gate
cable-stayed	cables run straight from tower to deck	modern river crossings

Triangles hold their shape; squares do not. Tacoma Narrows (1940) twisted apart in a 40 mph wind: **resonance**.

Buildings

- **Post and lintel** (Stonehenge, Greek temples) → **arch, vault, dome** (Rome: the keystone locks the arch) → **flying buttress** (Gothic cathedrals take the thrust outside) → **steel frame** and **curtain wall** (Chicago, 1885) with Otis's **safety elevator** (1854).
- **Foundations** spread the load; soft ground needs piles or caissons (the Roeblings sank them for Brooklyn).
- **Tall buildings** fight wind: cross-bracing, a stiff core, setbacks, a **tuned mass damper** (Taipei 101), **base isolation** for earthquakes. Codes: fire ratings, exits, sprinklers.

MEMORY TRICK

Arch pushes out, cable pulls in

An **arch** is all compression and needs strong abutments; a **suspension** bridge is all tension and needs heavy anchorages. Match the material: stone for squeezing, steel for stretching.

3 ELECTRICITY, MAGNETS & ELECTRONICS

unit 4 · Volta, Ohm, Faraday, Morse

Ohm's law

Voltage (volts) pushes **current** (amps) through **resistance** (ohms). 9 V across 3 Ω → 3 A. Power P = V × I (watts).

$$V = I \times R$$

Circuits

- A **circuit** is a complete loop: source (battery) → wire → load (bulb) → back. A **switch** opens the loop; an open circuit does nothing; a **short circuit** is a loop with no load (danger).
- **Series:** one path; the same current everywhere; one bulb out, all out. **Parallel:** branches; each gets the full voltage; one out, the rest stay lit (house wiring).
- **Conductors** (copper, aluminum) let charge flow; **insulators** (rubber, plastic, glass) do not.
- **Safety:** never put anything in an outlet; water and electricity do not mix; fuses and breakers open when current is too high.

Magnets and motors

- Like poles push apart, unlike poles pull; the earth is a magnet and a **compass** points north.
- Oersted (1820): a current makes a **magnetic field**. A coil around iron is an **electromagnet**; a **relay** is an electromagnet that works a switch.
- Faraday (1831): a moving magnet makes a current (**induction**). A **generator** turns motion into electricity; a **motor** turns electricity into motion (the commutator keeps it spinning).
- **AC** (Tesla) travels far through **transformers**; **DC** (Edison, batteries) flows one way.

Components

Resistor limits current (color bands) · **LED** lights one way (long leg +) · **diode** one-way valve · **capacitor** stores charge · **transistor** a switch or amplifier (base, collector, emitter) · **integrated circuit** thousands of transistors on a chip.

Digital and code

- A **bit** is 0 or 1; **binary** counts in twos: 1011 = 8 + 2 + 1 = 11. **Logic gates** (AND, OR, NOT) with truth tables (Boole, Shannon).
- **Morse code** (1844): dots and dashes over a telegraph; SOS = ··· – – – ···.
- **Program:** an **algorithm** step by step; **loops** repeat, **conditionals** choose (if … then), **variables** store; a **bug** is a mistake to find.
- **Microcontroller** (Uno-style board, Raspberry Pi): GPIO pins read sensors and drive motors; **sensor → controller → actuator**.
- **Feedback:** a thermostat compares the **set point** with the reading and turns the heat on or off (closed loop).

MEMORY TRICK **Ohm's triangle**

Cover the one you want: V on top, I and R below. V = IR, I = V ÷ R, R = V ÷ I.

4 WATER, POWER & PUBLIC UTILITIES

unit 5 · the systems behind the tap and the switch

Clean water

1. **Source:** river, lake, well, aquifer; Roman aqueducts ran on a gentle **gradient**.
2. **Coagulation:** chemicals clump the dirt.
3. **Settling** and **filtration** through sand.
4. **Disinfection:** chlorine (measured in mg/L) kills germs.
5. **Water tower:** height gives pressure (about 0.43 psi per foot of head); pipes and pumps carry it home.

Wastewater

Sewers carry it to a treatment plant (Bazalgette's London sewers ended the Great Stink, 1858): screens, settling, bacteria eat the waste, disinfect, return clean water to the river.

Making electricity

- Nearly all power is a spinning **generator** (Faraday): steam from coal, gas or nuclear heat, falling water (**hydro** dams), wind turbines; solar panels make DC without spinning.
- **Transformers** step voltage up for the long transmission lines and down at the substation and the pole.
- The **grid** runs at 60 Hz; supply must match demand every second; **N-1** means it survives any one failure; a cascade caused the 2003 blackout.
- **Lineworkers** and plant operators keep it running; SCADA screens watch the system.

Roads and telephones

Roman roads: layered stone, cambered to shed water; macadam; asphalt and concrete. Bell's telephone (1876) turned sound into current; today **optical fiber** carries light pulses by total internal reflection, and the internet moves **packets** through data centers.

Units to know

Quantity	Unit
force	newton (N)
work, energy	joule (J); kilowatt-hour on the bill
power	watt (W) = J/s; horsepower ≈ 746 W
voltage, current, resistance	volt (V), ampere (A), ohm (Ω)
pressure	pascal (Pa), psi
flow rate	gallons or liters per minute
frequency	hertz (Hz), cycles per second
speed	m/s, mph; a ship's knot = 1.15 mph

MEMORY TRICK

Utilities are hidden engineering

Every faucet, outlet and streetlight sits at the end of a long chain of engineers, operators and lineworkers. Say thank you by learning how it works.

5 BOATS & SHIPS

unit 6 · Archimedes to the Titanic

Archimedes' principle

A thing floats when it displaces its own weight of water before it goes under. Steel sinks as a block but floats as a hollow hull: the hull displaces more water than the steel weighs.

buoyant force = weight of the water displaced

Density

density = $\frac{\text{mass}}{\text{volume}}$. Water is 1 g/cm^3; wood floats (about 0.6), stone sinks (about 2.7), a loaded ship's **average** density is below 1.

Stability

- The **center of gravity** (weight) must sit low; the **center of buoyancy** (the pushed-aside water) must be able to push it back upright.
- **Ballast** low in the hull lowers the center of gravity; the warship **Vasa** (1628) was top-heavy and capsized on her first sail. An **inclining test** checks a ship before launch.
- **Watertight compartments** and **bulkheads** limit flooding; the Titanic's were not tall enough (1912); SOLAS rules followed: lifeboats for all.

MEMORY TRICK **Low and wide floats**

Weight **low**, hull **wide**, and the boat rights itself. Weight high and narrow tips over.

Moving the ship

- **Sail:** a sail is a wing; a keel keeps the boat from sliding sideways; tacking zigzags into the wind.
- **Steam:** Fulton's paddle steamer (1807) → the **screw propeller**; the steam turbine (Parsons, 1897).
- **Drag:** skin friction and wave-making drag; a **bulbous bow** cancels the bow wave; **hull speed** limits a displacement hull.
- **Submarines** flood or blow ballast tanks to sink or rise (neutral buoyancy); pressure rises about 1 atmosphere every 10 m; by Boyle's law the air in the ballast tanks is squeezed to a smaller volume as the pressure rises.
- Liberty ships (1940s) were prefabricated in blocks; cold made their steel brittle: lesson learned.

6 FLIGHT, SPACE & ROBOTS

units 7–8 · the four forces, sense-think-act

The four forces of flight

Force	Direction	Made by
lift	up	the wing: an airfoil's curved top (camber) and angle of attack
weight	down	gravity on the mass
thrust	forward	propeller, jet, rocket
drag	backward	air resistance

Level flight: lift = weight, thrust = drag. **Pitch** (nose up/down, elevator), **roll** (wings, ailerons), **yaw** (nose left/right, rudder). Too steep an angle of attack **stalls** the wing.

How flight was learned

Montgolfier balloons (1783, hot air is less dense) → Cayley's gliders → Lilienthal → the Wrights' method: kites, a wind tunnel, data, wing warping, then powered flight at Kitty Hawk, Dec. 17, 1903. Gliders: **glide ratio** = distance ÷ height lost.

Jets, rockets, orbits

- A **propeller** is a spinning wing; a **jet** throws hot gas backward; a **rocket** carries its own oxygen and works in space (action–reaction). **Staging** drops empty tanks (Saturn V, Apollo 11, 1969).
- An **orbit** is falling and missing: fast enough sideways (about 17,500 mph low over the earth) that the ground curves away.
- **Helicopters:** a rotating wing; collective and cyclic controls; the tail rotor fights torque.
- **Drones:** four rotors, an IMU senses tilt, a feedback (PID) controller keeps it level; FAA rules and the TRUST test for fliers.

MEMORY TRICK **Lift needs airflow**

No air moving over the wing, no lift. A plane stalls when it is too slow or too steep, not when the engine stops: it can glide.

Robots

- **Sense → think → act:** sensors (light, touch, distance, temperature) → controller (the program) → actuators (motors, servos). Unimate (1961) to the Mars rovers.
- **Open loop** runs blind; **closed loop** uses **feedback** to correct itself: a line follower reads the floor and steers.
- **Autonomous** machines decide from sensor data; a **servo** turns to an angle on command; motors are driven by pulse-width modulation.
- Code it: an algorithm with loops (repeat), conditionals (if the sensor sees black, turn) and variables (speed).

Toy lab

The Frisbee is a spinning wing (gyroscopic stability); LEGO bricks hold by **clutch power** and precise **tolerance**; a Rubik's cube hides a core mechanism; a wind-up toy stores energy in a mainspring; a Slinky shows waves; a gyroscope precesses. Tear a toy down and draw how it works.